STATISTICAL PHYSICS FOR ANOMALOUS TRANSPORT IN PLASMAS

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Self-modulation of the turbulence amplitude and spontaneous generation of poloidal rotation.

We have investigated the origin of poloidal rotation, as arising from sources distinct from the Reynolds stress and/or ion-direct loss. We have shown that this important process which determines improved confinement regimes can have other sources than these traditional mechanisms.

- We have developed our model[1] (that is able to correctly represent the full nonlinearity of the ion-temperature-gradient driven instability (barotropic equation). We have shown that the turbulence envelope is poloidally non-uniform and that it can be the source for plasma poloidal rotation. We have done an analytical study of the stability of the solutions of the envelope equation; since the equation is nonlinear, powerful analytical instruments have been employed (algebro-geometrical method of integration on periodic domains, spectral analysis, hyperelliptic curves). We have determined the torque due to the nonuniform diffusion rate via the Stringer mechanism (T.E. Stringer, Phys.Rev.Lett.22 (1969) 770) and proved that the neoclassical viscosity due to the magnetic pumping is overcomeby the torque.
- We have shown[2] that plasma rotation can be generated at spatial scales intermediate between the Ion Temperature Gradient driven mode eddies and the Larmor radius scales ρ_s of the Hasegawa-Mima vortices (W. Horton and A. Hasegawa, Chaos 4 (1994) 227), *i.e.* $\approx \sqrt{L_n \rho_s}$ by a nonlinear mechanism determined by the scalar nonlinearity. We have obtained an exact analytical solution that describes these stationary periodic flows. This result compares very well with experimental measurements and numerical simulations. We have studied the stability of this solution analytically (by obtaining the dispersion relation of the perturbation around the analytical solution) and numerically (by simulation of the evolution of a perturbation of the analytical solution).

The analytical approach we have developed in this context is rather strong and general and we have successfully applied it to the study of coherent structures in plasmas generated by other equations [3],[4],[9],[10],[11],[12]. Other statistical methods were prepared for future studies[13],[14].

- Plasma rotation can be generated also by a transition induced by a noise in a turbulence that can have multiple scales. It was shown that this process is described by a Langevin equation with several equilibria. These transition processes were analysed analytically and numerically[5-7].

- Another origin of the transport barriers can be the structure of the magnetic field in tokamak[8].

Determination of the effects of the long-time correlations due to particle trapping in stochastic fields.

The approach developed in previous years for studying transport in stochastic fields, the decorrelation trajectory method, was used to study the nonlinearity determined by the ExB drift motion in magnetized plasmas. This motion determines a trapping process, which consists in particle trajectory winding around the contour lines of the turbulent potential. In previous work, we have quantitatively evaluated the effect of this trapping on individual trajectories and we have shown that it determines a class of anomalous transport regimes at large Kubo numbers. During the year 2003, we have continued these test particle studies of transport and have shown that, besides the above effect, the trapping determines coherence in the stochastic motion and trajectory structures.

- We have developed a more powerful approach [15],[19] the nested subensemble method, which can determine much more statistical information about test particle trajectories. It is able to determine the dispersion of the trajectories and their probability distribution function in the subensembles, besides the average trajectory. We have shown that the trapping generates trajectory structures similar to fluid vortices and we have determined their statistical properties [15],[16],[19]. The structures appear around the maxima and the minima of the stochastic potential. We have shown that the trajectories contained in such structures have completely different statistical properties compared to other trajectories. Their dispersion saturates at a value of the order of the size of the structure and the probability distribution function evolves to a non-Gaussian equilibrium function. The trajectories which are not in such structures have a continuously increasing dispersion and a non-Gaussian probability that does not saturate. Thus, only these trajectories contribute to the transport while the trapped trajectories have quasi-coherent behaviour. The relative dispersion of pairs of trajectories was also studied and it was shown that an anomalous clump effect appears which is different for trapped and free trajectories. In the first case the clump time is very long compared to the quasi-linear result, while in the second case it is practically zero.

  These studies demonstrate that trapping yields quasi-coherent behaviour of a part of the trajectories (trajectory structures), long time correlations and memory effects (and thus non-Markovian behaviour), and anomalous diffusion regimes in the presence of a decorrelation mechanism.
- A computer code for determining the average, the dispersion and the probability distribution of the trajectories was developed and tested. A code for determining the statistical properties of the distance between trajectories was also developed. A series of runs were performed.
- Another important result of the new method was to validate the results of the decorrelation trajectory method. It was shown that the much improved approach, the nested subensemble method, which takes into account the fluctuations of the trajectories in the subensembles, yields very similar results for the correlation of the Lagrangian velocity and for the time-dependent diffusion coefficient. The

average trajectories in the subensembles obtained by the two methods are however completely different.

- We have continued the study of the transport of collisional particles in stochastic magnetic fields using the decorrelation trajectory method[17].
- We have also shown that the shape of the Eulerian correlation of the stochastic potential (or equivalently the spectrum of the turbulence) influences the transport scaling in the trapping regime [18],[20].

The work performed under these topics belong to the Subtask **"**Validation of physics-based transport models**"** from the Task 5 **"**First Principle Based Physics Understanding**"** of **"Physics R&D Needs for the EU Fusion Programme".** They are also related to the Subtask **"**ITB scenarios**"** from Task 3: **"**Issues for further improvement of ITER operation, or required to prepare later modifications**".**

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